Ultralow Noise, Low Distortion, Audio Op Amp

FEATURES

- Voltage Noise: 1.2nV/√Hz Max at 1kHz
  0.9nV/√Hz Typ at 1kHz
- Voltage and Current Noise 100% Tested
- Gain-Bandwidth Product: 40MHz Min
- Slew Rate: 10V/µs Min
- Voltage Gain: 2 Million Min
- Low THD at 10kHz, A_V = –10, R_L = 600Ω: 0.002%
  $V_O = 7V_{RMS}$
- Low IMD, CCIF Method, A_V = +10: 0.002%
  R_L = 600Ω
  $V_O = 7V_{RMS}$

APPLICATIONS

- High Quality Audio Preamplifiers
- Low Noise Microphone Preamplifiers
- Very Low Noise Instrumentation Amplifiers
- Low Noise Frequency Synthesizers
- Infrared Detector Amplifiers
- Hydrophone Amplifiers
- Low Distortion Oscillators

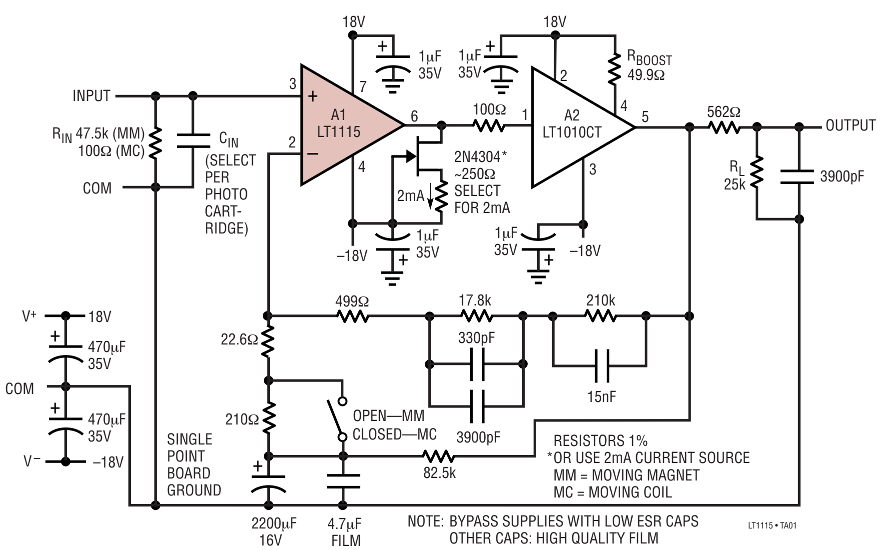
DESCRIPTION

The LT®1115 is the lowest noise audio operational amplifier available. This ultralow noise performance (0.9nV/√Hz at 1kHz) is combined with high slew rates (>15V/µs) and very low distortion specifications.

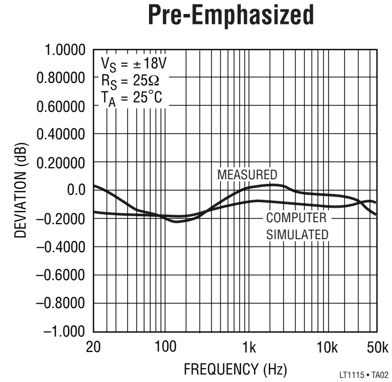
The RIAA circuit shown below using the LT1115 has very low distortion and little deviation from ideal RIAA response (see graph).

TYPICAL APPLICATION

RIAA Phonograph Preamplifier (40/60db Gain)



Measured Deviation from RIAA Response. Input at 1kHz = $1mV_{RMS}$ Pre-Emphasized



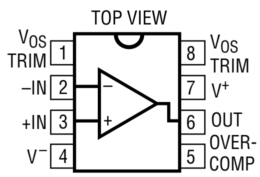
ABSOLUTE MAXIMUM RATINGS

(Note 1)

Supply Voltage .... ±22V
Differential Input Current (Note 5) .... ±25mA
Input Voltage .... Equal to Supply Voltage
Output Short-Circuit Duration .... Indefinite

Operating Temperature Range .... 0°C to 70°C
Storage Temperature Range .... –65°C to 150°C
Lead Temperature (Soldering, 10 sec) .... 300°C

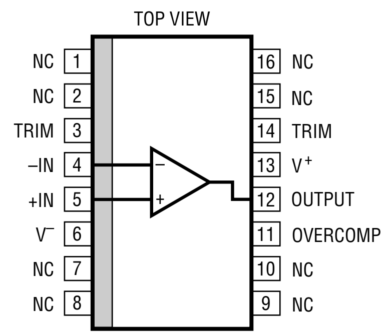
PACKAGE DESCRIPTION



N PACKAGE
8-LEAD PDIP
T_{JMAX} = 115°C, θ_{JA} = 130°C/W

ORDER PART NUMBER

LT1115CN8



SW PACKAGE
16-LEAD PLASTIC SO
T_{MAX} = 115°C, θ_{JA} = 130°C/W

ORDER PART NUMBER

LT1115CSW

LT1115 • POI01

Consult LTC Marketing for parts specified with wider operating temperature ranges.

ELECTRICAL CHARACTERISTICS

V_S = ±18V, T_A = 25°C, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
THD	Total Harmonic Distortion at 10kHz	A_V = –10, V_O = 7V_{RMS}, R_L = 600		< 0.002		%
IMD	Inter-Modulation Distortion (CCIF)	A_V = 10, V_O = 7V_{RMS}, R_L = 600		< 0.0002		%
V_{OS}	Input Offset Voltage	(Note 2)		50	200	µV
I_{OS}	Input Offset Current	V_{CM} = 0V		30	200	nA
I_B	Input Bias Current	V_{CM} = 0V		±50	±380	nA
e_n	Input Noise Voltage Density	f_O = 10Hz f_O = 1000Hz, 100% tested		1.0 0.9	 1.2	nV/√Hz nV/√Hz
	Wideband Noise	DC to 20kHz		120		nV_{RMS}
	Corresponding Voltage Level re 0.775V			–136		dB
i_n	Input Noise Current Density (Note 3)	f_O = 10Hz f_O = 1000Hz, 100% tested		4.7 1.2	 2.2	pA/√Hz pA/√Hz
	Input Resistance Common Mode Differential Mode			 250 15		 MΩ kΩ
	Input Capacitance			5		pF
	Input Voltage Range		±13.5	±15.0		V

ELECTRICAL CHARACTERISTICS $V_S = \pm18V$, $T_A = 25°C$, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
CMRR	Common Mode Rejection Ratio	$V_{CM} = \pm13.5V$	104	123		dB
PSRR	Power Supply Rejection Ratio	$V_S = \pm4V$ to $\pm19V$	104	126		dB
A_{VOL}	Large-Signal Voltage Gain	$R_L \geq 2k\Omega$, $V_O = \pm14.5V$ $R_L \geq 1k\Omega$, $V_O = \pm13V$ $R_L \geq 600\Omega$, $V_O = \pm10V$	2.0 1.5 1.0	20 15 10		V/μV V/μV V/μV
V_{OUT}	Maximum Output Voltage Swing	No Load $R_L \geq 2k\Omega$ $R_L \geq 600\Omega$	±15.5 ±14.5 ±11.0	±16.5 ±15.5 ±14.5		V V V
SR	Slew Rate	$A_{VCL} = -1$	10	15		V/μs
GBW	Gain-Bandwidth Product	$f_O = 20kHz$ (Note 4)	40	70		MHz
Z_O	Open Loop Output Impedance	$V_O = 0$, $I_O = 0$		70		Ω
I_S	Supply Current			8.5	11.5	mA

The ● denotes specifications which apply over the full operating temperature range, otherwise specifications are at $T_A = 25°C$. $V_S = \pm18V$, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage	(Note 2)	●		75	280	μV
$\Delta V_{OS}/\Delta T$	Average Input Offset Drift				0.5		μV/°C
I_{OS}	Input Offset Current	$V_{CM} = 0V$	●		40	300	nA
I_B	Input Bias Current	$V_{CM} = 0V$	●		±70	±550	nA
	Input Voltage Range		●	±13	±14.8		V
CMRR	Common Mode Rejection Ratio	$V_{CM} = \pm13V$	●	100	120		dB
PSRR	Power Supply Rejection Ratio	$V_S = \pm4.5V$ to $\pm18V$	●	100	123		dB
A_{VOL}	Large-Signal Voltage Gain	$R_L \geq 2k\Omega$, $V_O = \pm13V$ $R_L \geq 1k\Omega$, $V_O = \pm11V$	●	1.5 1.0	15 10		V/μV V/μV
V_{OUT}	Maximum Output Voltage Swing	No Load $R_L \geq 2k\Omega$ $R_L \geq 600\Omega$	●	±15 ±13.8 ±10	±16.3 ±15.3 ±14.3		V V V
I_S	Supply Current		●		9.3	13	mA

Note 1: Absolute Maximum Ratings are those values beyond which the life of a device may be impaired.

Note 2: Input Offset Voltage measurements are performed by automatic test equipment approximately 0.5 sec after application of power.

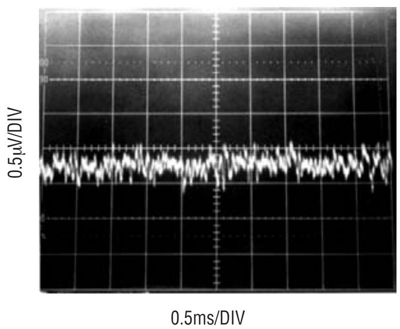
Note 3: Current noise is defined and measured with balanced source resistors. The resultant voltage noise (after subtracting the resistor noise on an RMS basis) is divided by the sum of the two source resistors to obtain current noise.

Note 4: Gain-bandwidth product is not tested. It is guaranteed by design and by inference from the slew rate measurement.

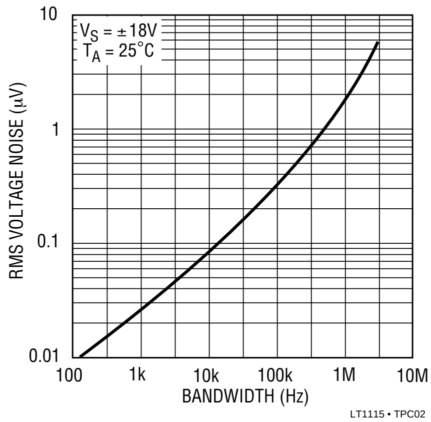
Note 5: The inputs are protected by back-to-back diodes. Current limiting resistors are not used in order to achieve low noise. If differential input voltage exceeds ±1.8V, the input current should be limited to 25mA.

TYPICAL PERFORMANCE CHARACTERISTICS

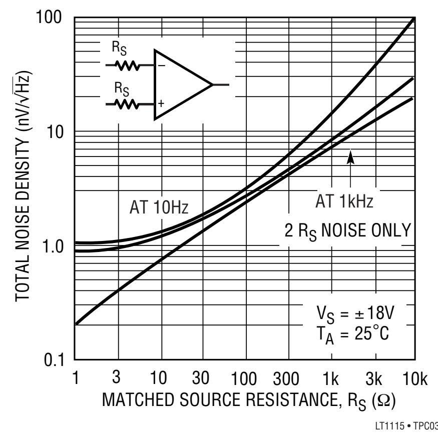
Wideband Noise, DC to 20kHz



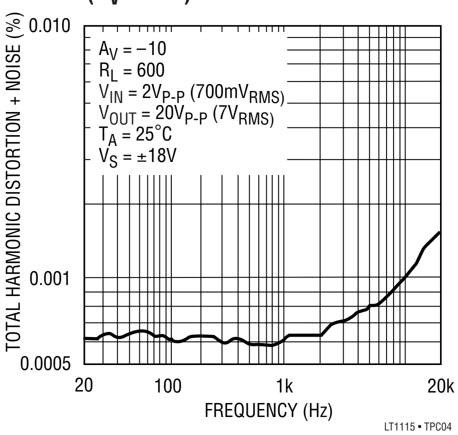
Wideband Voltage Noise (0.1Hz to Frequency Indicated)



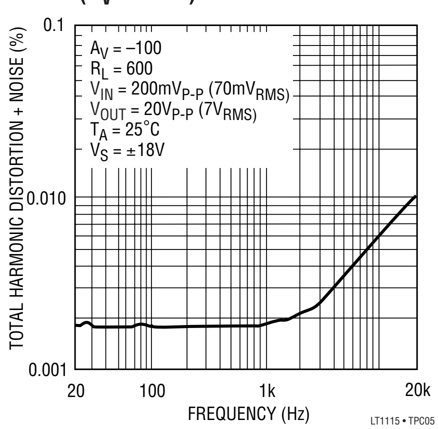
Total Noise vs Matched Source Resistance



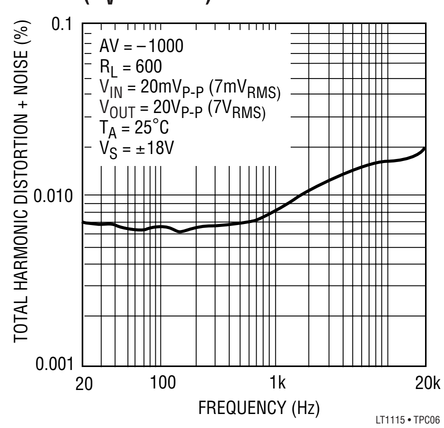
THD + Noise vs Frequency (A_V = –10)



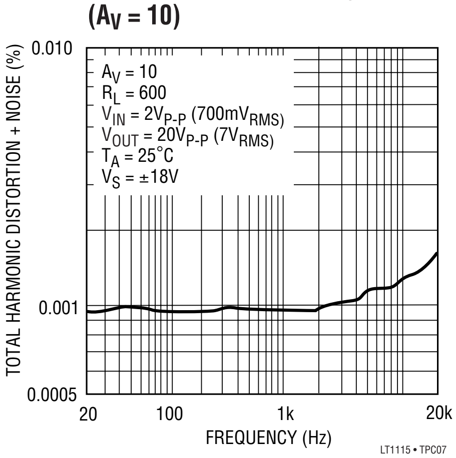
THD + Noise vs Frequency (A_V = –100)



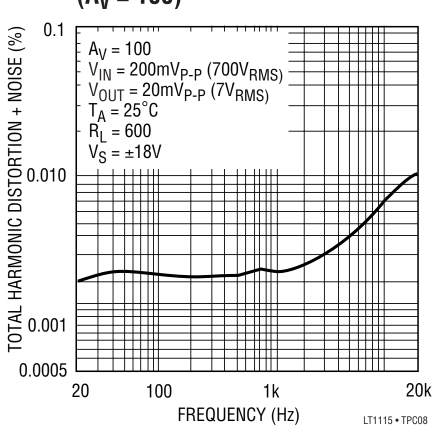
THD + Noise vs Frequency (A_V = –1000)



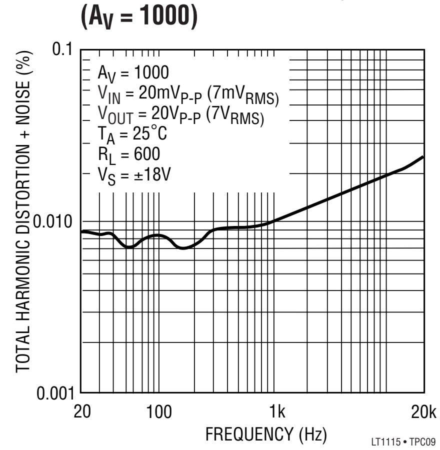
THD + Noise vs Frequency (A_V = 10)



THD + Noise vs Frequency (A_V = 100)

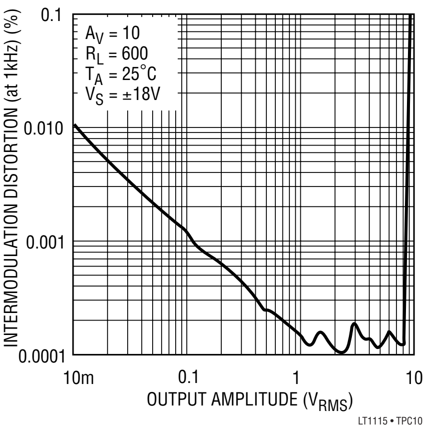


THD + Noise vs Frequency (A_V = 1000)

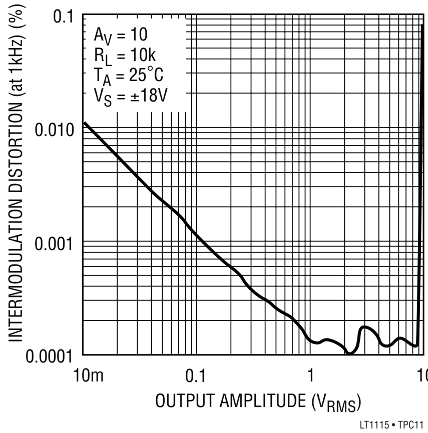


TYPICAL PERFORMANCE CHARACTERISTICS

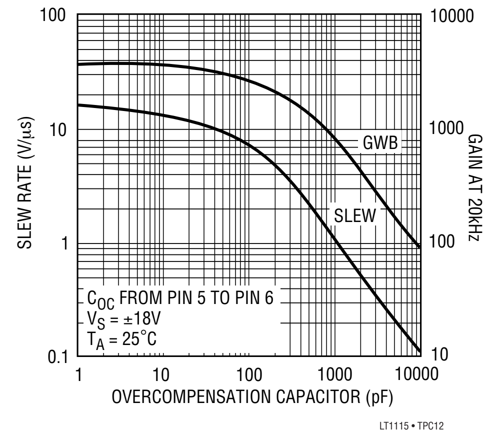
CCIF IMD Test (Twin Equal Amplitude Tones at 13 and 14kHz)*



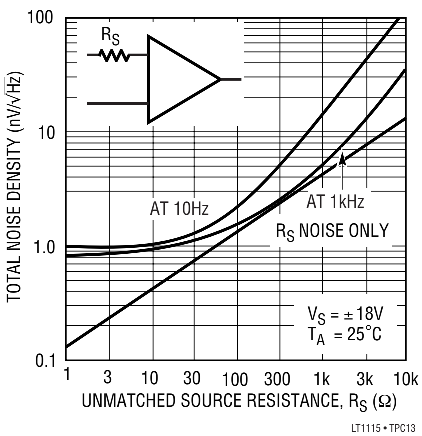
CCIF IMD Test (Twin Equal Amplitude Tones at 13 and 14kHz)*



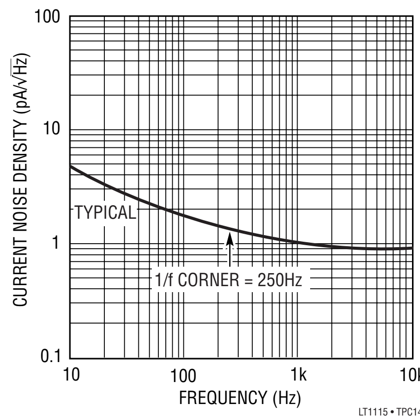
Slew Rate, Gain-Bandwidth-Product vs Overcompensation Capacitor



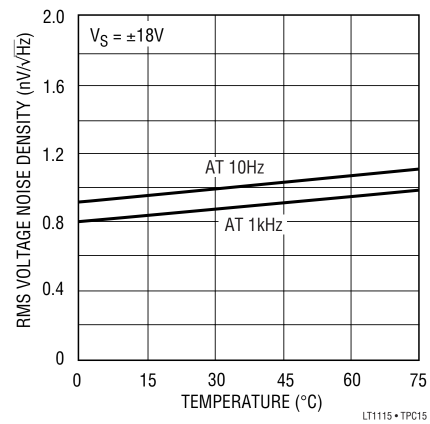
Total Noise vs Unmatched Source Resistance



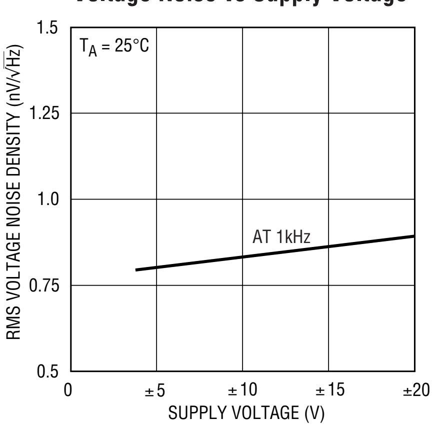
Current Noise Spectrum



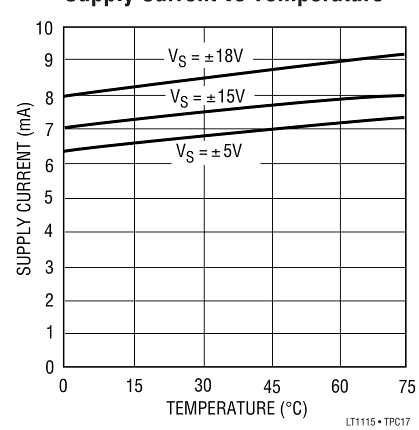
Voltage Noise vs Temperature



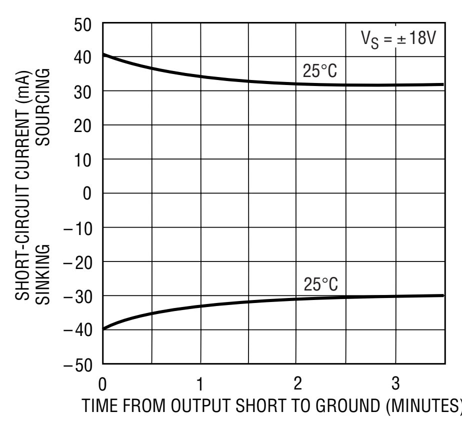
Voltage Noise vs Supply Voltage



Supply Current vs Temperature



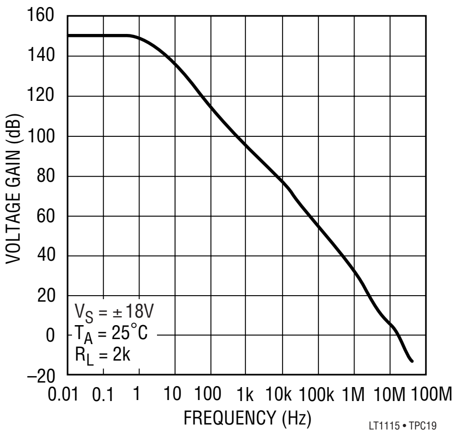
Output Short-Circuit Current vs Time



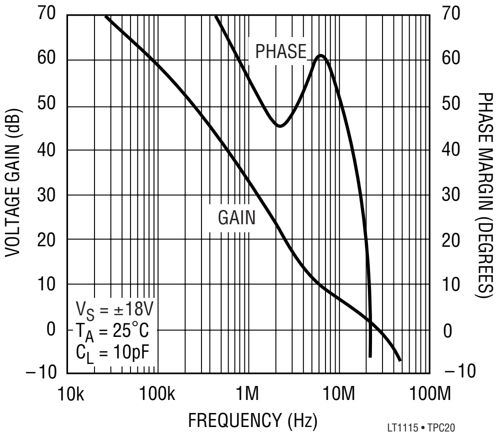
*See CCIF Test Note at end of "Typical Performance Characteristics".

TYPICAL PERFORMANCE CHARACTERISTICS

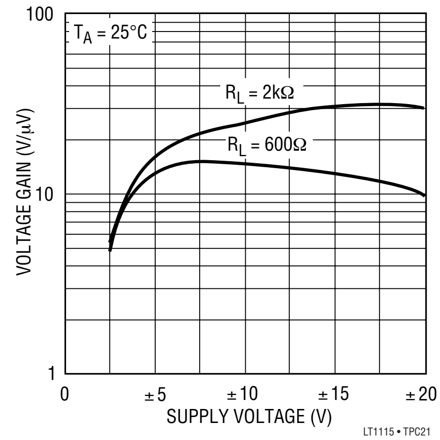
Voltage Gain vs Frequency



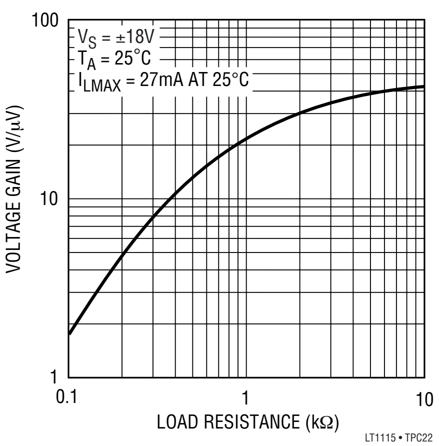
Gain, Phase vs Frequency



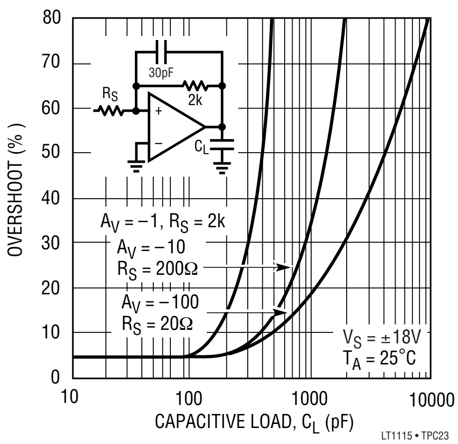
Voltage Gain vs Supply Voltage



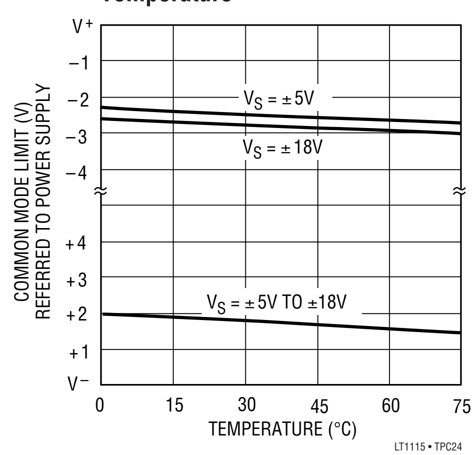
Voltage Gain vs Load Resistance



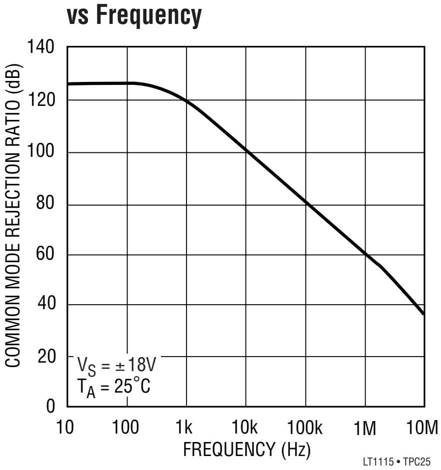
Capacitance Load Handling



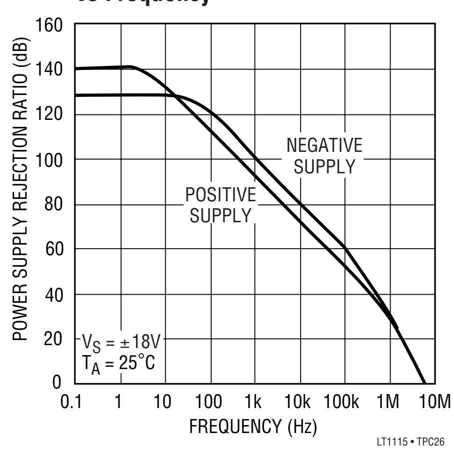
Common Mode Limit Over Temperature



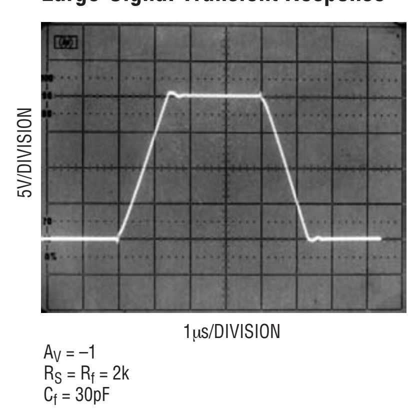
Common Mode Rejection Ratio vs Frequency



Power Supply Rejection Ratio vs Frequency



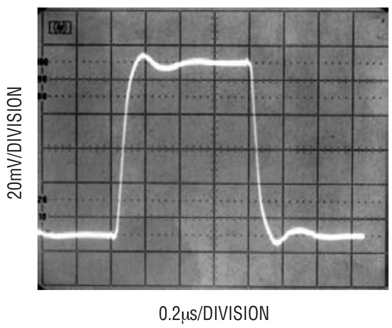
Large-Signal Transient Response



$A_V = -1$
$R_S = R_f = 2k$
$C_f = 30pF$

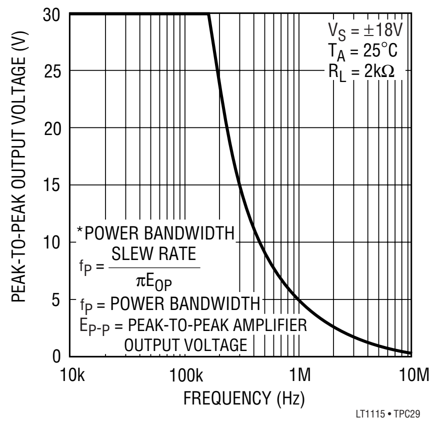
TYPICAL PERFORMANCE CHARACTERISTICS

Small-Signal Transient Response

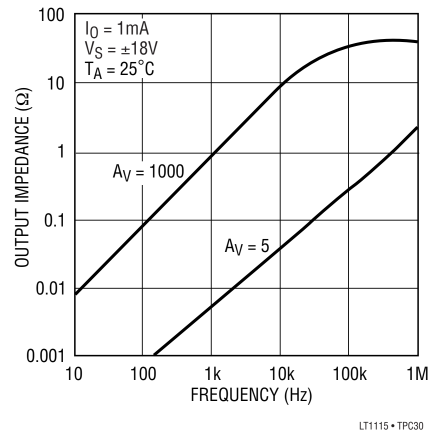


$A_V = -1$,
$R_S = R_f = 2k\Omega$
$C_f = 30pF$
$C_L = 80pF$

Maximum Output vs Frequency (Power Bandwidth*)



Closed-Loop Output Impedance



CCIF Testing

Note: The CCIF twin-tone intermodulation test inputs two closely spaced equal amplitude tones to the device under test (DUT). The analyzer then measures the intermodulation distortion (IMD) produced in the DUT by measuring the difference tone equal to the spacing between the tones.

The amplitude of the IMD test input is in sinewave peak equivalent terms. As an example, selecting an amplitude of 1.000V will result in the complex IMD signal having the same 2.828V peak-to-peak amplitude that a 1.000V sinewave has. Clipping in a DUT will thus occur at the same input amplitude for THD + N and IMD modes.

APPLICATIONS INFORMATION

The LT1115 is a very high performance op amp, but not necessarily one which is optimized for universal application. Because of very low voltage noise and the resulting high gain-bandwidth product, the device is most applicable to relatively high gain applications. Thus, while the LT1115 will provide notably superior performance to the 5534 in most applications, the device may require circuit modifications to be used at very low noise gains. The part is not generally applicable for unity gain followers or inverters. In general, it should always be used with good low impedance bypass capacitors on the supplies, low impedance feedback values, and minimal capacitive loading. Ground plane construction is recommended, as is a compact layout.

Voltage Noise vs Current Noise

The LT1115's less than $1nV/\sqrt{Hz}$ voltage noise matches that of the LT1028 and is three times better than the lowest voltage noise heretofore available (on the LT1007/1037). A necessary condition for such low voltage noise is operating the input transistors at nearly 1mA of collector currents, because voltage noise is inversely proportional to the square root of the collector current. Current noise, however, is directly proportional to the square root of the collector current. Consequently, the LT1115's current noise is significantly higher than on most monolithic op amps.

APPLICATIONS INFORMATION

Therefore, to realize truly low noise performance it is important to understand the interaction between voltage noise (e_n), current noise (i_n) and resistor noise (r_n).

Total Noise vs Source Resistance

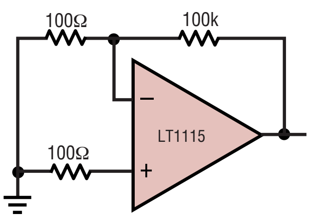
The total input referred noise of an op amp is given by

$$e_t = [e_n^2 + r_n^2 + (i_n R_{eq})^2]^{1/2}$$

where R_{eq} is the total equivalent source resistance at the two inputs

and $r_n = \sqrt{4kTR_{eq}} = 0.13\sqrt{R_{eq}}$ in $nV/\sqrt{Hz}$ at 25°C

As a numerical example, consider the total noise at 1kHz of the gain of 1000 amplifier shown below.



$$R_{eq} = 100\Omega + 100\Omega||100k \approx 200\Omega$$

$$r_n = 0.13\sqrt{200} = 1.84nV/\sqrt{Hz}$$

$$e_n = 0.85nV/\sqrt{Hz}$$

$$i_n = 1.0pA/\sqrt{Hz}$$

$$e_t = [0.85^2 + 1.84^2 + (1.0 \times 2.0)^2]^{1/2} = 2.04nV/\sqrt{Hz}$$

$$\text{output noise} = 1000\ e_t = 2.04\mu V/\sqrt{Hz}$$

At very low source resistance (R_{eq} < 40Ω) voltage noise dominates. As R_{eq} is increased resistor noise becomes the largest term—as in the example above—and the LT1115's voltage noise becomes negligible. As R_{eq} is further increased, current noise becomes important. At 1kHz, when R_{eq} is in excess of 20kΩ, the current noise component is larger than the resistor noise. The Total Noise vs Matched Source Resistance plot in the Typical Performance Characteristics section, illustrates the above calculations.

The plot also shows that current noise is more dominant at low frequencies, such as 10Hz. This is because resistor noise is flat with frequency, while the 1/f corner of current noise is typically at 250Hz. At 10Hz when R_{eq} > 1kΩ, the current noise term will exceed the resistor noise.

When the source resistance is unmatched, the Total Noise vs Unmatched Source Resistance plot should be consulted. Note that total noise is lower at source resistances below 1kΩ because the resistor noise contribution is less. When R_S > 1kΩ total noise is not improved, however. This is because bias current cancellation is used to reduce input bias current. The cancellation circuitry injects two correlated current noise components into the two inputs. With matched source resistors the injected current noise creates a common-mode voltage noise and gets rejected by the amplifier. With source resistance in one input only, the cancellation noise is added to the amplifier's inherent noise.

In summary, the LT1115 is the optimum amplifier for noise performance—provided that the source resistance is kept low. The following table depicts which op amp manufactured by Linear Technology should be used to minimize noise—as the source resistance is increased beyond the LT1115's level of usefulness.

Best Op Amp for Lowest Total Noise vs Source Resistance

SOURCE RESISTANCE (NOTE 1)	BEST OP AMP AT LOW FREQ (10Hz)	WIDEBAND (1kHz)
0 to 400Ω	LT1028/1115	LT1028/1115
400Ω to 4kΩ	LT1007/1037	LT1028/1115
4kΩ to 40kΩ	LT1001*	LT1007/1037
40kΩ to 500kΩ	LT1012*	LT1001*
500kΩ to 5MΩ	LT1012* or LT1055	LT1012*
> 5M	LT1055	LT1055

Note 1: Source resistance is defined as matched or unmatched, e.g., R_S = 1kΩ means: 1kΩ at each input, or 1kΩ at one input and zero at the other.

*These op amps are best utilized in applications requiring less bandwidth than audio.

TYPICAL APPLICATIONS

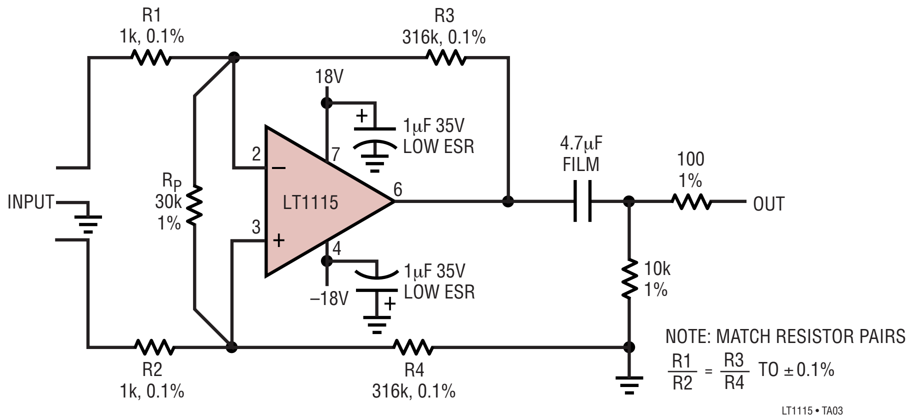
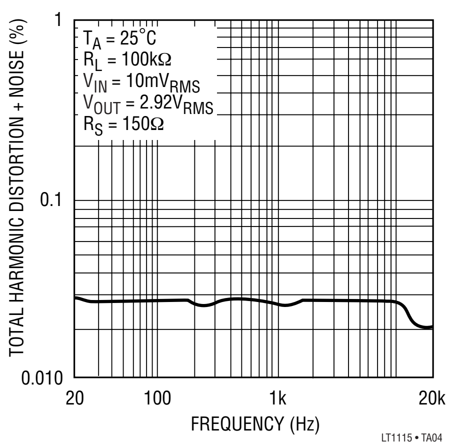


Figure 1. Balanced Transformerless Microphone Preamp

THD + Noise vs Frequency (Figure 1)



TYPICAL APPLICATIONS

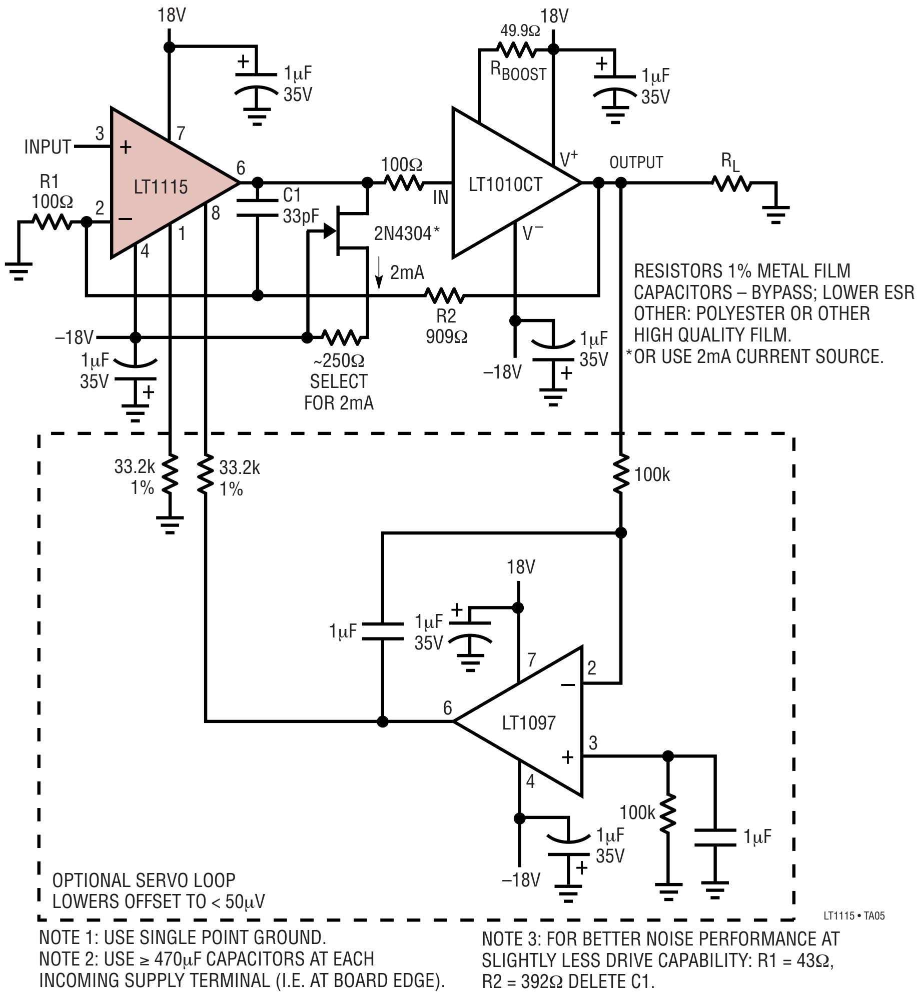
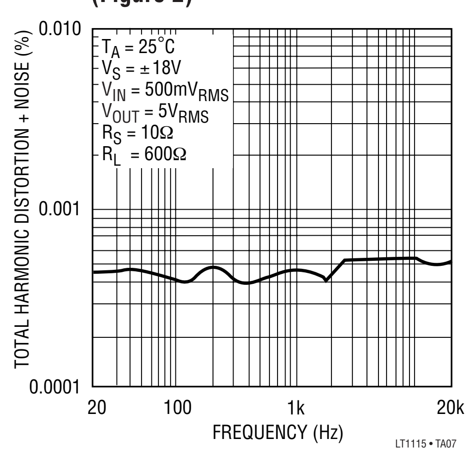


Figure 2. Low Noise DC Accurate x 10 Buffered Line Amplifier

THD + Noise vs Frequency (Figure 2)



TYPICAL APPLICATIONS

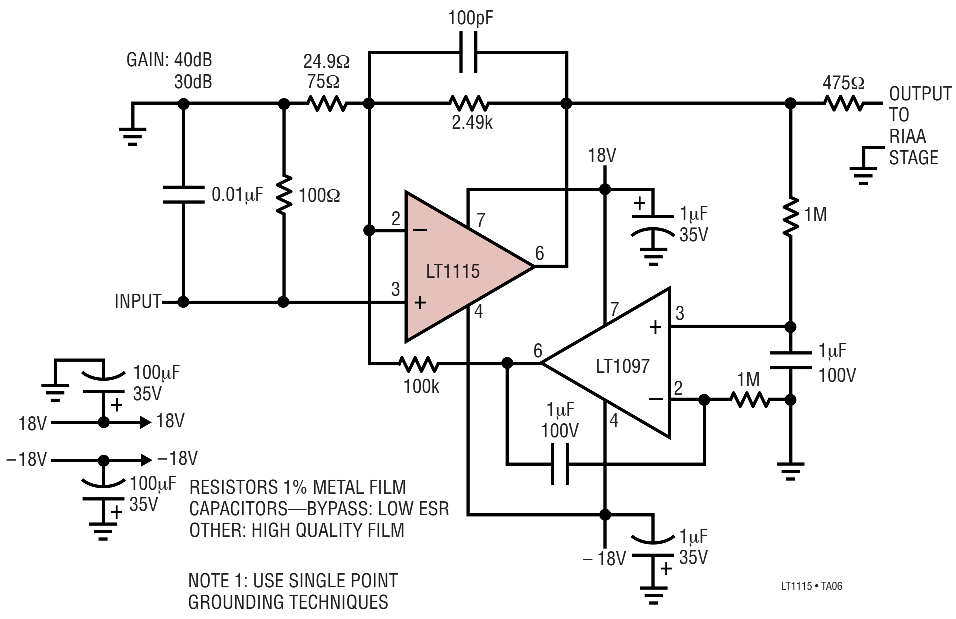
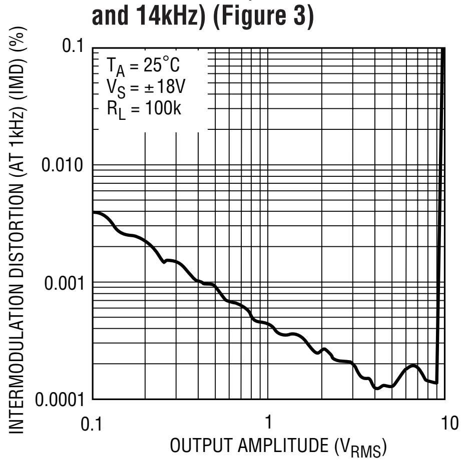
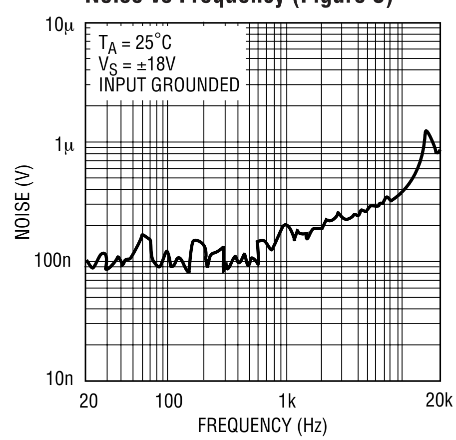


Figure 3. RIAA Moving Coil "Pre-Pre" Amplifier (40/30dB Gain Low Noise Servo'd Amplifier)

CCIF IMD Test (Twin Tones at 13 and 14kHz) (Figure 3)



Noise vs Frequency (Figure 3)



NOTE: NOISE AT 1kHz REFERRED TO INPUT ~2nV

LT1115 • TA09

TYPICAL APPLICATIONS

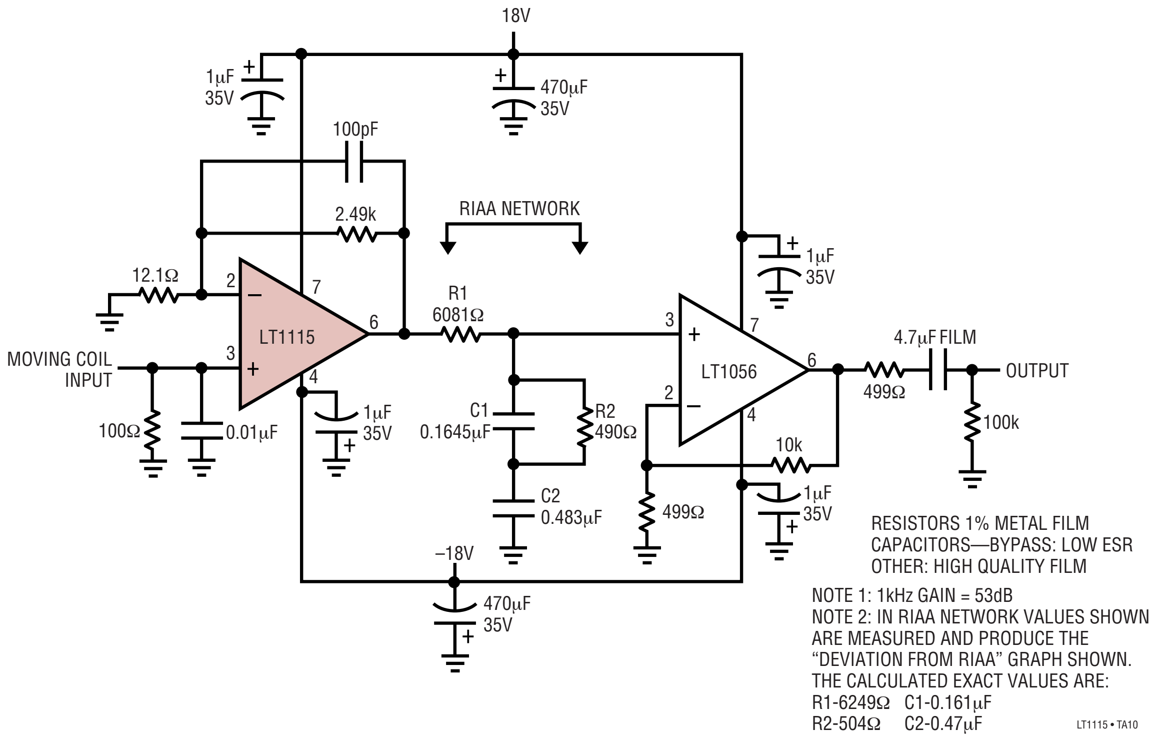
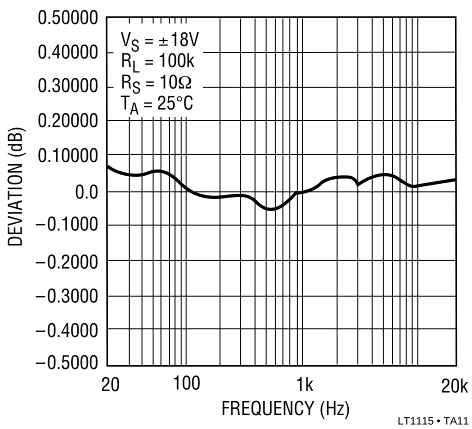
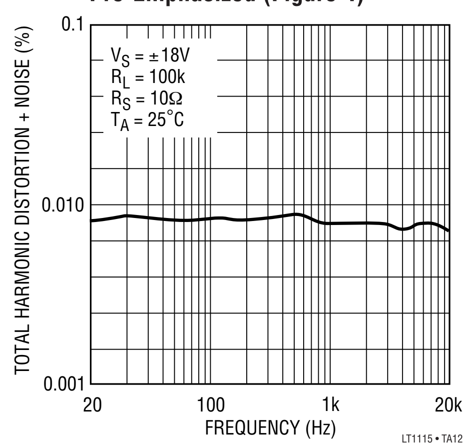


Figure 4. Moving Coil Passive RIAA Phonograph Pre-Amp

Deviation from RIAA Response
Input at 1kHz = 232μV$_{RMS}$
Pre-Emphasized (Figure 4)



THD + Noise vs Frequency
Input at 1kHz = 232μV$_{RMS}$
Pre-Emphasized (Figure 4)



TYPICAL APPLICATIONS

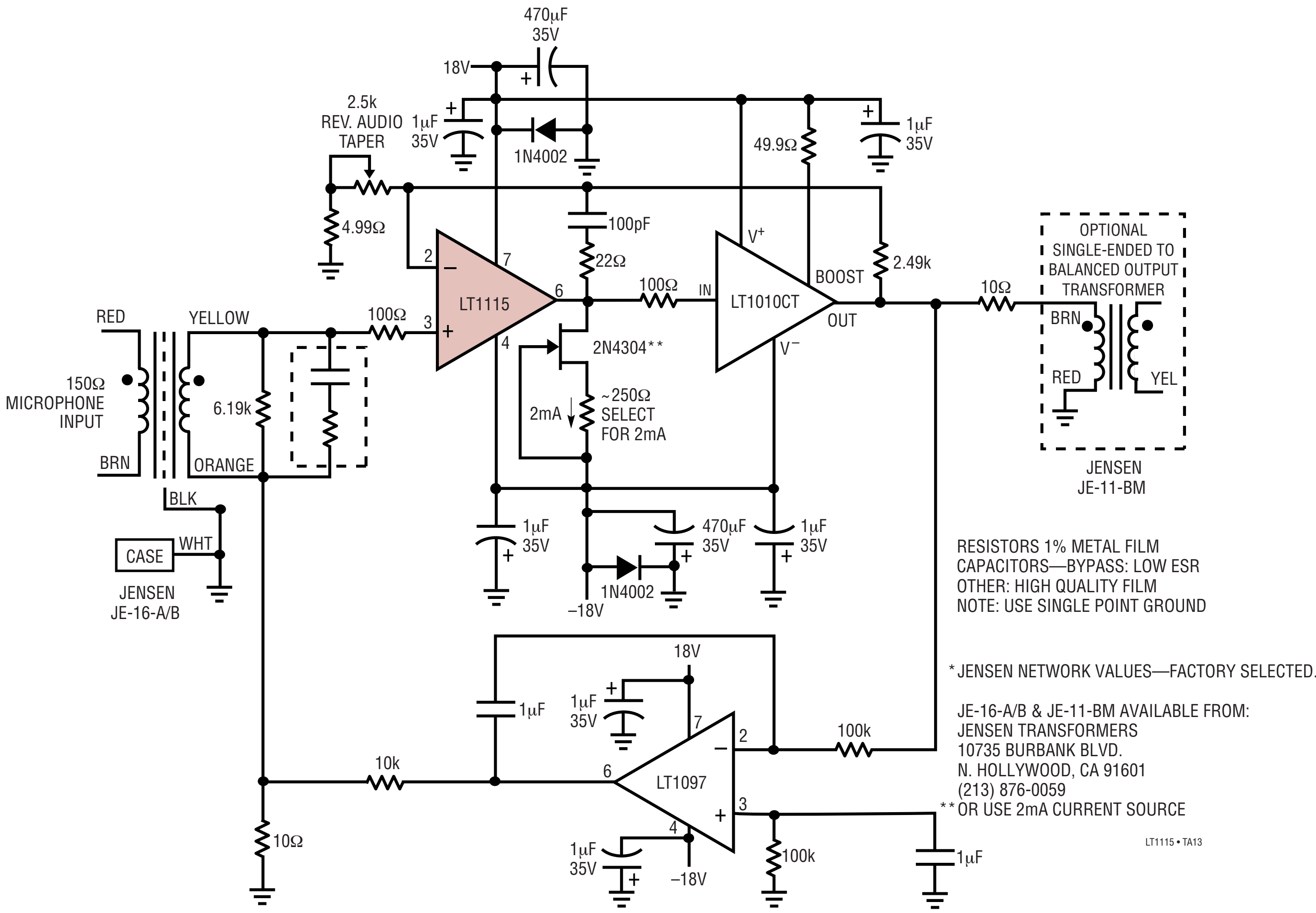
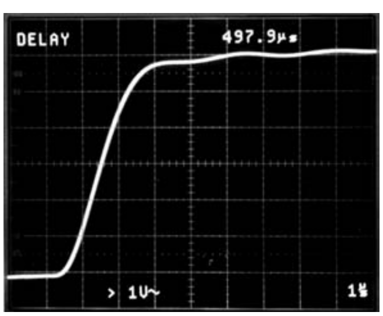


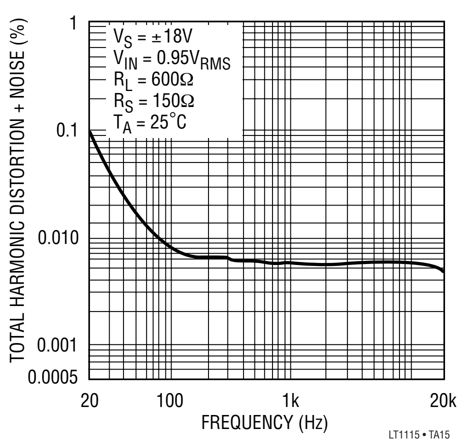
Figure 5. High Performance Transformer Coupled Microphone Pre-Amp

Risetime of High Performance Transformer Coupled Microphone Pre-Amp (Figure 5)

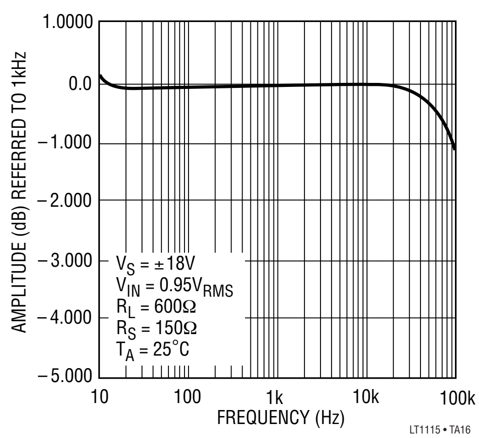


RISETIME OF PRE-AMP
A_V = 20dB
V_{IN} = 400mV
2kHz SQUARE WAVE MEASURED AT SINGLE-ENDED OUTPUT BEFORE TRANSFORMER

THD + Noise vs Frequency (Gain = 20dB) Balanced In/Balanced Out (Figure 5)



Frequency Response (Gain = 20dB) Balanced In/Balanced Out (Figure 5)



TYPICAL APPLICATIONS

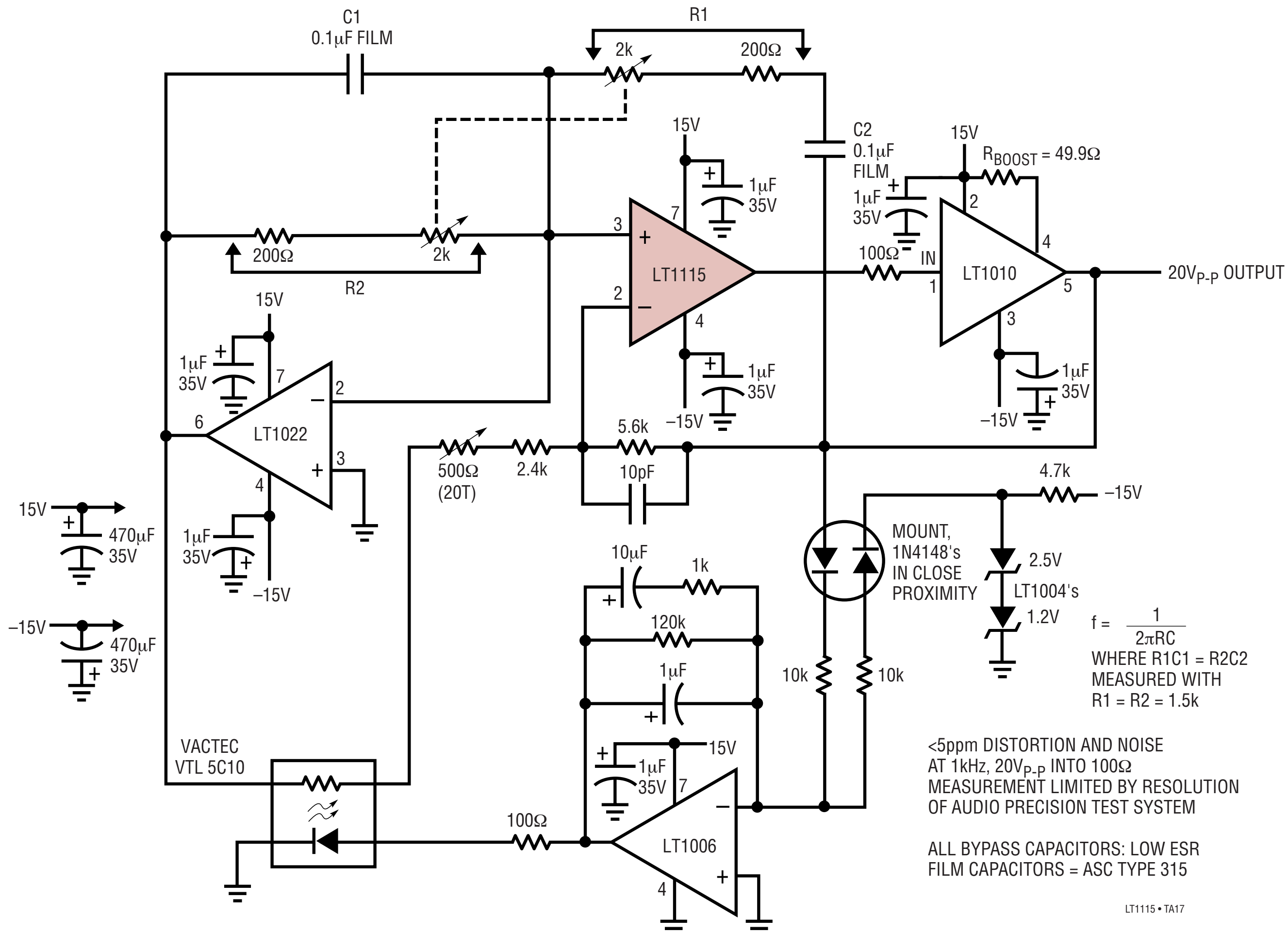
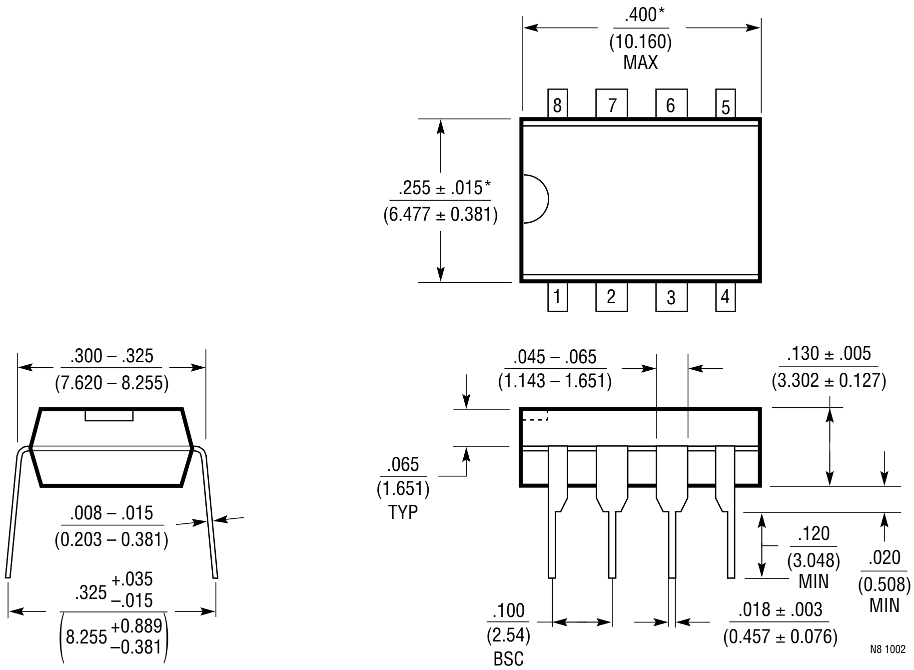


Figure 6. Ultralow THD Oscillator (Sine Wave) (< 5ppm Distortion)

PACKAGE DESCRIPTION

N8 Package
8-Lead PDIP (Narrow .300 Inch)
(Reference LTC DWG # 05-08-1510)

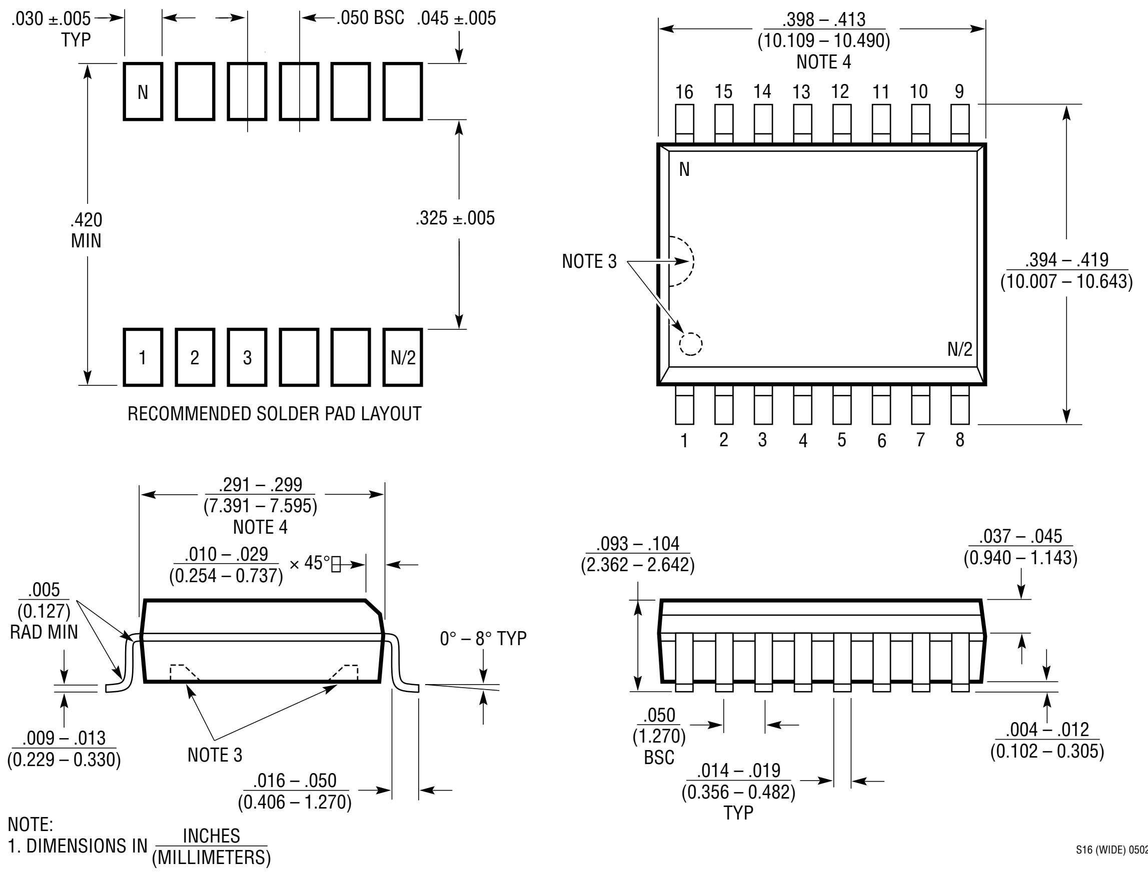


NOTE:
1. DIMENSIONS ARE $\frac{\text{INCHES}}{\text{MILLIMETERS}}$

*THESE DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED .010 INCH (0.254mm)

PACKAGE DESCRIPTION

SW Package
16-Lead Plastic Small Outline (Wide .300 Inch)
(Reference LTC DWG # 05-08-1620)



NOTE:
1. DIMENSIONS IN $\frac{\text{INCHES}}{\text{(MILLIMETERS)}}$
2. DRAWING NOT TO SCALE
3. PIN 1 IDENT, NOTCH ON TOP AND CAVITIES ON THE BOTTOM OF PACKAGES ARE THE MANUFACTURING OPTIONS. THE PART MAY BE SUPPLIED WITH OR WITHOUT ANY OF THE OPTIONS
4. THESE DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS. MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED .006" (0.15mm)

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